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ORIGINAL PAPER

Effects of slope aspects on forest compositions, community structures and soil properties in natural temperate forests of Garhwal Himalaya

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Abstract: The present study was undertaken in seven natural forest types of temperate zone (1500 to 3100 m, a.s.l.) of Garhwal Himalaya to understand the effects of slope aspects viz., north-east (NE), north-west (NW), south-east (SE) and south-west (SW), on the forest structure, composition and soil characteristics of each selected forest type. The sample plots in each forest type were laid out by using stratified random approach. The indices i.e., the Importance Value Index, Shannon-Wiener diversity index, Simpson's concentration of Dominance, Simpson diversity index, Pielou equitability and Margalef species richness index were calculated statistically using standard softwares to elucidate the differences in forest structure and composition of forest types on different slope aspects of the sites. The composite soil samples were taken from each forest stand and the physico-chemical properties of the soil i.e., moisture content (MC), water holding capacity (WHC), pH, organic carbon (OC), phosphorus (P), potassium (K) and available nitrogen (N) were analyzed. The results show that the higher values of total basal cover (74.4 $m^2 \cdot ha^{-1}$ in *Quercus semecarpifolia* forest), Concentration of dominance (0.85 in *Pinus roxburghii* forest) and Tree diversity (1.81 in *Quercus floribunda* forest) in the forests were recorded in the northern aspects. MC (40.8% in *Quercus leucotrichophora* forest), WHC (48.9% in *Cupressus torulosa* forest), OC (3.8% in *Cedrus deodara* forest), P (31.9 $kg \cdot ha^{-1}$ in *Quercus leucotrichophora* forest) and N (1.0% in *Pinus roxburghii* forest) had also higher values in the soils of northern aspects. Consequently the higher productivity of the forests was also noticed on the northern aspects.

Keywords: diversity; stem density; forest composition; aspects; soil nutrients

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Introduction

The diversity of trees is fundamental to total forest biodiversity (Huang et al. 2003). At large scales, species diversity is generally found to be related to climate and forest productivity (Rahbek 2005). Franklin et al. (1989) proposed that long-term productivity of natural forest ecosystems with high tree species diversity may be greater than that of forests with low tree species diversity due to the increasing ecosystem resilience to disturbance. Slobodkin and Sanders (1969) opined that species richness of any communities has the function of predictability of the environment. Therefore, tree species diversity tends to increase as the environment becomes more favourable and more predictable (Putman 1994).

The altitude and slope aspect play a key role in determining the temperature regime of any sites. Within one altitude the cofactors like topography, slope aspect, inclination of slope and soil type also affect the forest composition (Shank and Noorie 1950). Differences in insolation period at various altitudes may occur according to slope aspect of site, thereby forming a range of microclimates in multifaceted landscapes. Consequently, microclimate is often linked to soil moisture and distribution of particular plant communities (Holland and Steyn 1975) on different slope aspects. In Himalayas, the north-facing slopes are relatively cooler as they receive less sunlight while the south-facing slopes are considered as warmer and drier due to longer insolation (longer exposure) period during the day. The community structure and forest productivity parameters studied in mountains are overestimated in most of the ecological studies as they do not take into consideration the slope aspects. Although studies on effect of altitude on the community composition and productivity of forests of Garhwal Himalaya have been done by numerous workers (Sharma et al. 2009a, 2009b), the effect of slope aspect has not been studied in detail, except few attempts were made by Baduni and Sharma (1999), Sharma and Baduni (2000) and Mishra et al. (2000). Under the backdrop of the afo-

resaid facts, the present study was undertaken in seven major undisturbed temperate forest types of Garhwal Himalaya to understand the effects of slope aspects on the forest composition, community structure and soil status.

Materials and methods

Study area

Seven major natural forest types were selected for the study after the reconnaissance survey (Table 1). The climate of these sites is typical moist temperate type, which receives moderate to high snowfall from December to February on higher elevations. In the study sites, the year is represented by three main seasons, viz., the cool and relatively dry winter (December to March); the warm and dry summer (mid-April to June); and a warm and wet period (July to mid-September) called as the monsoon or rainy season. Meteorological data were taken from State Observatories of Gopeshwar and Pauri cities (Table 1). Average annual rainfall in these areas ranged between 1125 mm and 2350 mm. The rainfall in rainy season accounts for about three-quarters of the annual rainfall. Apart from these main seasons, the transitional periods interconnecting rainy and winter, and winter and summer are referred to as autumn (October to November) and spring (February to March). At lower altitudes, the fires in the *Pinus roxburghii* forest were common during the warm and dry months (from mid-April to mid-June) especially on the drier southern aspects.

Table 1. General details of the forest types

FT	Forest type*	Type (Champion & Seth 1968)	Altitude (m, a.s.l.)	Locality	Location	Mean temperature ranges (°C)		Mean annual rainfall (mm)
						Max	Min	
FT 1	*Abies pindrow* Spach. (Fir) Forest	12/C_2 b	2600-3100	Dudhatoli	29° 43' N, 79° 46' E	20.8 (May)	1.2 (Jan)	1825
FT 2	*Quercus semecarpifolia* Sm. (Kharsu Oak) Forest	12/C_2a	2500-3000	Pauri	30° 09' N, 78° 45' E	18.6 (May)	2.8 (Dec)	2350
FT 3	*Quercus floribunda* Lindle (Moru Oak) Forest	12/C_1b	2300-2600	Dudhatoli	29° 43' N, 79° 46' E	27.5 (Jun)	4.0 (Jan)	1475
FT 4	*Cupressus torulosa* Don. (Himalayan Cypress) Forest	12/E_1	2100-2500	Jhandidhar	30° 08' N, 78° 46' E	25.5 (Jun)	5.5 (Jan)	1125
FT 5	*Cedrus deodara* Lond. (Deodar) Forest	12/C_1c	2200-2500	Binsar	30° 00' N, 79° 09' E	26.4 (May)	5.7 (Jan)	1300
FT 6	*Quercus leucotrichophora* A. Camus (Banj Oak) Forest	12/C_1a	1600-2100	Buvakhal	30° 08' N, 78° 47' E	28.7 (May)	6.8 (Jan)	1450
FT 7	*Pinus roxburghii* Sarg. (Chir Pine) Forest	9/C_1b	1500-1800	Thalisain	30° 02' N, 79° 03' E	32.0 (May)	11.2 (Dec)	1320

Notes: * Forest types were used as FT1 to FT7 in the successive tables.

Sampling and analysis of the data

The selected forest types were named according to the classification given by Champion and Seth (1968). The study was conducted in 7 forest types on four aspects viz., north-east, north-west, south-east and south-west each (total 28 stands). Physiographic factors i.e., altitude and slope aspect across different forest types were measured by GPS (Garmin, Rino-130) and Abney's level. A total of 280 plots (ten plots on each forest stand i.e., 28×10) measuring 10 m × 10 m each were sampled. Plots were located by stratified random approach and stratification was allowed equal repetition. The trees were identified with the help of Flora of the District Garhwal North West Himalaya (Gaur 1999) and others. Trees were defined to be individuals with dbh (diameter at breast height i.e., 1.37 m) of ≥ 10 cm as per methodology given by Knight (1963). Diameter at breast height (dbh) was taken for the determination of tree basal cover and was calculated as πr^2, where r is the radius. Total basal cover (TBC) is the sum of basal cover of all species present in the forest. The data were quantitatively analyzed for stem density, frequency and abundance following Curtis and McIntosh (1950). Stem density and TBC were converted to per hectare (ha) for extrapolation of the results. Basal cover ($m^2 \cdot ha^{-1}$) was used to determine the relative dominance of a tree species. The Importance Value Index (Phillips 1959), Shannon-Wiener Diversity index (Shannon and Wiener 1963), Simpson's Concentration of dominance (Simpson 1949), Simpson diversity index (Simpson 1949), equitability (Pielou 1966) and species richness (Margalef 1958) were calculated with the following formulae:

$$I_{\mathrm{VI}} = (R_{\mathrm{F}} + R_{\mathrm{D}} + R_{\mathrm{Do}}) \quad (1)$$

$$\overline{H} = -\sum_{i=1}^{s} \frac{n_i}{n} \log_2 \frac{n_i}{n} \quad (2)$$

$$C_{\mathrm{d}} = \sum_{i=1}^{s} P_i^2 \quad (3)$$

$$\sum_{i=1}^{s} P_i^2 = \sum \frac{n_i}{n} \quad (4)$$

$$D = 1 - C_d \quad (5)$$

$$E_{\mathrm{p}} = \frac{\overline{H}}{\overline{H}_{\max}} \quad (6)$$

$$\overline{H}_{\max} = \ln S \tag{7}$$

$$S_R = \frac{S-1}{\ln(N)} \tag{8}$$

where, I_{VI} is Importance Value Index, R_F the relative frequency, R_D the relative stem density, and R_{Do} is the relative dominance. $\overline{H}$ is Shannon-Wiener diversity index, n_i is the Importance Value Index value of a species, n is the sum of total Importance Value Index values of all species in that forest type, C_d is Simpson's Concentration of dominance, D is Simpson diversity, and E_p is Pielou's equitability. S is the total number of species in forest type. ln$S$ is natural log of total number of species in forest type. S_R is Margalef index of species richness (number of species per unit area) and N is total number of individuals.

From each forest stand, five composite soil samples were collected from 0-30-cm depth of soil, packed in polythene bags and brought to the laboratory for analysis of physical and chemical properties. Walkley and Black's rapid titration method (Walkley 1947) was used for organic carbon estimation. Available phosphorus in the soil was determined by Olsen et al. (1954) method. Potassium was extracted by neutral normal ammonium acetate method (Morwin and Peach 1951) and was determined by the flame photometer. Total nitrogen was measured by using the standard Kjeldhal procedure (Bremner and Mulvaney 1982). The pH of the soil sample was measured by control dynamics digital pH meter in a 1:2 soil/water suspension. The water holding capacity (WHC) of the soil samples was determined as per Mishra (1968). The soil moisture was calculated as:

$$M = \frac{L}{D} \times 100 \tag{9}$$

where, M is the moisture percentage, L the loss of weight on drying, and D is the dry weight of soil. The one-way analysis of variance (ANOVA) was used to test the differences between data of soil analysis. The Tukey post-hoc test was used to test differences among means when the F-test was significant ($p \le 0.05$). Significant differences are indicated by using different letters behind the means. Statistical analysis was performed using Minitab version 15.0 Software.

Results

Community structure and species diversity

Analytical characters of vegetation for different forest types are placed in the Table 2. The highest values of Total Basal Cover (TBC) of dominant tree species were recorded as 51.0 $m^2 \cdot ha^{-1}$ (*A. pindrow* in *A. pindrow* forest), 57.3 $m^2 \cdot ha^{-1}$ (*Q. semecarpifolia* in *Q. semecarpifolia* forest), 38.3 $m^2 \cdot ha^{-1}$ (*Q. floribunda* in *Q. floribunda* forest), 56.5 $m^2 \cdot ha^{-1}$ (*C. torulosa* in *C. torulosa* forest), 61.0 $m^2 \cdot ha^{-1}$ (*C. deodara* in *C. deodara* forest), 38.6 $m^2 \cdot ha^{-1}$ (*Q. leucotrichophora* in *Q. leucotrichophora* forest) and 60.3 $m^2 \cdot ha^{-1}$ (*P. roxburghii* in *P. roxburghii* forest) on NE aspect in each forest type. Whereas, stem density was found to be maximum on NE aspect in *A. pindrow* forest (390 individual·ha^{-1} of *A. pindrow*) and *Q. leucotrichophora* forest (1240 individual·ha^{-1} of *Q. leucotrichophora*), on NW aspect in *C. deodara* forest (410 individual·ha^{-1} of *C. deodara*), on SE aspect in *Q. floribunda* forest (340 individual·ha^{-1} of *Q. floribunda*) and *C. torulosa* forest (580 individual·ha^{-1} of *C. torulosa*) and on SW aspect in *Q. semecarpifolia* forest (520 individual·ha^{-1} of *Q. semecarpifolia*) and *P. roxburghii* forest (980 individual·ha^{-1} of *P. roxburghii*). Maximum I_{VI} values for dominant species were recorded on NE aspect in *A. pindrow* forest (208.4), on NW aspect in *C. deodara* forest (231.7) and *Q. leucotrichophora* forest (266.4), on SE aspect in *Q. floribunda* forest (181.1) and *C. torulosa* forest (222.9), and on SW aspect in *Q. semecarpifolia* forest (250.1) and *P. roxburghii* forest (300.0). Invariably in all the forest types total TBC showed descending trend as NE>NW>SE>SW. Maximum TBC was recorded on NE aspect of *Q. semecarpifolia* forest (74.4 $m^2 \cdot ha^{-1}$), while minimum on SE aspect of *P. roxburghii* forest (20.6 $m^2 \cdot ha^{-1}$). Total stem density did not show any specific trend. Maximum total stem density was recorded on NE aspect of *Q. leucotrichophora* forest (1360 individual·ha^{-1}), whereas, minimum on NE aspect of *C. deodara* forest (380 individual·ha^{-1}).

Values of different diversity indices for various forest types and slope aspects are placed in Table 3. Concentration of dominance (C_d) was found to be maximum on NE aspect of *P. roxburghii* forest (0.85) and minimum on SW aspect of *Q. floribunda* forest (0.34). Whereas, values of Simpson diversity index ranged from a maximum of 0.66 on SW aspect of *Q. floribunda* forest to a minimum of 0.21 on NW aspect of *Q. leucotrichophora* forest. Tree diversity or $\overline{H}$ values were between 1.81 on NW aspect of *Q. floribunda* forest and 0.41 on NE aspect of *P. roxburghii* forest. Equatability values were observed to be maximum on NW aspect of *Q. semecarpifolia* forest (0.90) and minimum on NW aspect of *Q. leucotrichophora* forest (0.39). The highest value of Margalef index for species richness was recorded on NW aspect of *A. pindrow* forest (0.73), while lowest on NE aspect of *Q. leucotrichophora* forest (0.14).

Soil analysis

The results of soil analysis are shown in Table 4. The available soil moisture ranged between 12.2% and 40.8%. The mean soil moisture content (MC) was found to be the highest on NE aspect, followed by NW aspect in all the forest types. Statistically soils on northern aspects had higher moisture content than soils on southern aspects (P = 0.05). All the forest types had the lowest moisture content available on the SW aspect except *Q. semecarpifolia* forest, where moisture content was the lowest on SE aspect. The values of Water Holding Capacity (WHC) were found to be ranging between 17.3% and 48.9%. Northern and southern aspects had significant differences in WHC for all the forest types. Soils on NE aspect had higher WHC than soils on other slope aspects. The pH values were recorded between 4.2 and 6.7. Statistically there was not much variation in soil pH on different slope aspects in all the forest types. The values of organic carbon (OC) ranged from 0.9% to 3.8%. In *A. pindrow* forest and *Q. semecarpifolia* forest, no statistically significant variation in organic carbon was observed on different slope aspects, but in

other forest types statistically significant differences were recorded (p = 0.05). All the forest types had higher OC on NE aspect, followed by NW aspect, whereas invariably lowest OC was recorded on the SW aspect in all the forest types. The common order of OC among different slope aspects was NE>NW>SE>SW in all the forest types. The values of phosphorus, potassium and available nitrogen ranged from 31.9 kg·ha^{-1} to 7.2 kg·ha^{-1}, 712.0 kg·ha^{-1} to 72.7 kg·ha^{-1} and 0.31 % to 0.06 %, respectively. Although in all the forest types statistically significant differences were observed on different slope aspects (P = 0.05), no specific trend in rest of the cases was observed in the availability of nutrients on different slope aspects.

Table 2. Analytical characters of the forest types

FT	Species	North East (NE)†			North West (NW)†			South East (SE)†			South West (SW)†		
		Stem density*	TBC	I_{VI}	Density*	TBC	I_{VI}	Stem density*	TBC	I_{VI}	Stem density*	TBC	I_{VI}
FT1	*Abies pindrow*	390	51.0	208.4	310	42.8	194.7	380	35.3	197.7	330	30.9	166.5
	Aesculus indica	-	-	-	-	-	-	60	2.1	36.2	-	-	-
	Quercus semecarpifolia	80	11.6	55.3	40	7.3	36.2	30	7.3	30.8	90	13.7	70.3
	Rhododendron arboreum	60	1.8	36.3	50	1.8	32.7	20	4.3	22.6	130	4.6	63.3
	Taxus baccata	-	-	-	30	0.6	21.4	-	-	-	-	-	-
	Ulmus wallichiana	-	-	-	20	0.8	15.0	10	0.3	12.6	-	-	-
	Total	530	64.4	300	450	53.3	300	500	49.3	299.9	550	49.2	300.1
FT2	*Abies pindrow*	120	10.4	63.4	-	-	-	-	-	-	-	-	-
	Cedrus deodara	-	-	-	-	-	-	20	1.5	18.2	-	-	-
	Ilex dipyrena	-	-	-	-	-	-	20	0.6	15.9	10	0.5	10.3
	Quercus floribunda	-	-	-	260	5.8	93.9	-	-	-	-	-	-
	Quercus semecarpifolia	310	57.3	179.9	360	47.9	206.1	360	33.4	207.0	520	31.5	250.1
	Rhododendron arboreum	110	6.7	56.6	-	-	-	120	3.7	58.8	50	3.4	39.6
	Total	540	74.4	299.9	620	53.7	300	520	39.2	299.9	580	35.4	300
FT3	*Abies pindrow*	60	2.6	37.5	-	-	-	-	-	-	-	-	-
	Acer acuminatum	-	-	-	70	2.1	35.0	-	-	-	-	-	-
	Fraxinus micrantha	-	-	-	-	-	-	20	0.2	8.7	-	-	-
	Ilex dipyrena	-	-	-	-	-	-	-	-	-	60	1.5	29.8
	Lindera pulcherrima	110	1.9	46.4	-	-	-	-	-	-	-	-	-
	Prunus cornuta	-	-	-	40	0.8	22.0	-	-	-	-	-	-
	Quercus floribunda	250	38.3	169.7	250	37.6	171.5	340	23.0	181.1	290	18.5	148.7
	Quercus leucotrichophora	-	-	-	-	-	-	-	-	-	180	5.8	75.5
	Rhododendron arboreum	70	5.9	46.4	70	5.7	46.7	120	5.8	67.5	80	3.1	46.0
	Symplocos crataegoides	-	-	-	50	1.1	24.8	80	1.8	42.7	-	-	-
	Total	490	48.7	300	480	47.3	300	560	30.8	300	610	28.9	300
FT4	*Cedrus deodara*	-	-	-	90	8.4	57.9	200	7.2	77.1	20	0.0	9.2
	Cupressus torulosa	470	56.5	183.6	480	54.8	214.7	580	33.1	222.9	560	19.8	160.5
	Myrica esculenta	10	0.1	5.3	10	0.1	6.8	-	-	-	-	-	-
	Pinus wallichiana	190	2.4	58.3	-	-	-	-	-	-	220	4.5	69.0
	Quercus semecarpifolia	80	1.9	28.4	-	-	-	-	-	-	20	0.3	9.8
	Rhododendron arboreum	90	3.6	24.3	30	0.5	20.6	-	-	-	190	3.3	51.4
	Total	840	64.5	299.9	610	63.8	300	780	40.3	300	1010	27.9	299.9
FT5	*Cedrus deodara*	280	61.0	223.0	410	48.4	231.7	400	46.2	222.8	230	36.1	207.1
	Cupressus torulosa	-	-	-	-	-	-	-	-	-	110	8.4	60.2
	Lyonia ovalifolia	30	0.4	25.1	-	-	-	-	-	-	-	-	-
	Pinus wallichiana	-	-	-	50	1.3	40.5	-	-	-	-	-	-
	Quercus floribunda	-	-	-	-	-	-	50	1.3	33.2	-	-	-
	Quercus leucotrichophora	70	3.7	51.8	-	-	-	20	0.2	14.9	-	-	-
	Rhododendron arboreum	-	-	-	40	1.5	27.7	50	1.9	29.1	50	1.6	32.7
	Total	380	65.1	299.9	500	51.2	299.9	520	49.6	300	390	46.1	300
FT6	*Myrica esculenta*	120	1.3	40.0	30	0.6	21.0	60	2.2	44.2	-	-	-
	Pinus roxburghii	-	-	-	-	-	-	50	0.9	35.7	50	1.3	34.6
	Quercus leucotrichophora	1240	38.6	260.0	800	29.2	266.4	430	17.5	220.2	520	15.9	208.0
	Rhododendron arboreum	-	-	-	10	1.2	12.6	-	-	-	90	3.6	57.3
	Total	1360	39.9	300	840	31.0	300	540	20.6	300.1	660	20.8	299.9
FT7	*Lyonia ovalifolia*	-	-	-	-	-	-	20	0.3	10.7	-	-	-
	Myrica esculenta	30	1.3	24.3	-	-	-	-	-	-	-	-	-
	Pinus roxburghii	520	60.3	275.8	390	33.8	237.9	640	32.5	258.0	980	30.8	300.0
	Quercus leucotrichophora	-	-	-	110	2.4	62.1	50	1.0	31.5	-	-	-
	Total	550	61.6	300.0	500	36.2	300.0	710	33.8	300.0	980	30.8	300.0

Notes: *---- Stem density (individual·ha^{-1}); TBC is Total Basal Cover (m^2·ha^{-1}); I_{VI} is Importance Value Index; †Abbreviations NE, NW, SE and SW represent North-East, North-West, South-East and South-West aspects respectively in the successive tables.

Table 3. Diversity indices of the forest types on different slope aspects

Diversity indices	Aspect	FT1	FT2	FT3	FT4	FT5	FT6	FT7
Simpson's concentration of dominance (C_d)	NE	0.53	0.44	0.38	0.41	0.59	0.77	0.85
	NW	0.45	0.57	0.38	0.55	0.62	0.79	0.67
	SE	0.47	0.52	0.44	0.62	0.61	0.57	0.75
	SW	0.41	0.71	0.34	0.37	0.53	0.53	-
Simpson diversity index	NE	0.47	0.56	0.62	0.59	0.41	0.23	0.15
	NW	0.55	0.43	0.62	0.45	0.38	0.21	0.33
	SE	0.53	0.48	0.56	0.38	0.39	0.43	0.25
	SW	0.59	0.29	0.66	0.63	0.47	0.47	-
Shannon-Wiener diversity index ($\overline{H}$)	NE	1.18	1.37	1.67	1.41	1.05	0.57	0.41
	NW	1.61	0.89	1.81	1.19	0.99	0.61	0.74
	SE	1.57	1.29	1.47	0.82	1.19	1.09	0.70
	SW	1.44	0.77	1.75	1.72	1.18	1.18	-
Equitability (Pielou)	NE	0.75	0.86	0.84	0.69	0.67	0.57	0.40
	NW	0.69	0.90	0.78	0.60	0.63	0.39	0.74
	SE	0.68	0.65	0.74	0.82	0.61	0.69	0.44
	SW	0.91	0.49	0.87	0.74	0.75	0.75	-
Species richness (Maragelef Index)	NE	0.35	0.35	0.53	0.63	0.38	0.14	0.17
	NW	0.73	0.17	0.72	0.51	0.35	0.31	0.18
	SE	0.71	0.53	0.52	0.16	0.53	0.35	0.33
	SW	0.35	0.34	0.51	0.60	0.38	0.33	-

Table 4. Soil properties of the forest types on different slope aspects

Soil Property	Aspect	FT1	FT2	FT3	FT4	FT5	FT6	FT7
Moisture (%)	NE	37.5 a	21.9 a	23.2 a	23.0 a	23.4 a	40.8 a	19.4 b
	NW	38.5 a	16.5 c	22.8 a	21.2 a	23.3 ab	36.9 b	25.9 a
	SE	33.0 b	15.1 d	19.4 b	15.8 b	20.8 bc	25.2 c	18.9 b
	SW	32.5 b	19.7 b	16.5 b	13.2 b	19.2 c	21.7 c	12.2 c
Water Holding Capacity (%)	NE	44.2 a	47.5 a	32.4 b	48.9 a	46.4 a	46.3 a	33.5 a
	NW	44.7 a	40.3 b	38.6 a	40.6 b	46.6 a	35.8 b	31.3 a
	SE	38.9 b	42.3 b	32.5 b	33.6 c	42.5 b	34.1 bc	31.7 a
	SW	38.6 b	32.7 c	22.5 c	31.8 c	40.4 b	32.6 c	17.3 b
pH	NE	5.4 b	5.9 b	5.9 a	4.6 b	6.4 a	6.2 a	5.8 a
	NW	5.5 ab	6.1 b	6.1 a	4.7 b	6.0 c	6.1 a	5.9 a
	SE	5.4 b	5.8 b	6.1 a	5.9 a	5.8 c	5.4 b	5.9 a
	SW	5.7 a	6.7 a	6.1 a	4.2 c	6.3 ab	5.5 b	5.5 b
Organic carbon (%)	NE	2.2 a	2.6 a	2.2 a	2.6 a	3.8 a	2.5 a	2.2 a
	NW	2.2 a	2.5 a	2.0 ab	2.5 ab	3.7 a	2.4 ab	1.1 b
	SE	2.1 a	2.4 a	1.9 b	2.3 ab	3.0 b	2.3 b	1.0 b
	SW	2.0 a	2.3 a	1.6 c	2.2 b	2.1 c	1.9 c	0.9 b
Phosphorus ($kg \cdot ha^{-1}$)	NE	16.0 a	10.6 b	23.2 a	18.4 a	9.3 a	31.9 a	13.3 c
	NW	12.4 b	7.2 c	13.8 c	17.0 a	9.9 a	11.5 c	18.5 b
	SE	10.7 b	11.7 b	22.7 a	11.5 b	8.8 a	26.1 b	16.7 ab
	SW	14.8 ab	14.3 a	17.9 b	17.9 a	8.0 a	14.9 c	21.5 a
Potassium ($kg \cdot ha^{-1}$)	NE	228.0 a	119.9 ab	356.7 c	149.7 a	477.6 a	603.8 a	231.3 b
	NW	164.9 c	97.3 b	636.7 b	130.6 ab	416.8 b	86.1 c	281.0 a
	SE	145.3 bc	72.7 c	712.0 a	111.9 bc	408.4 b	579.2 a	204.7 c
	SW	183.8 b	135.1 a	377.3 c	102.3 c	249.3 c	206.6 b	103.1 d
Available nitrogen (%)	NE	0.06 b	0.20 c	0.17 a	0.21 ab	0.31 a	0.20 a	1.00 a
	NW	0.18 a	0.22 b	0.19 a	0.22 a	0.30 a	0.21 a	0.18 b
	SE	0.19 a	0.19 bc	0.17 a	0.19 bc	0.24 b	0.19 a	0.91 a
	SW	0.19 a	0.22 a	0.14 b	0.18 c	0.17 c	0.16 b	0.09 b

Notes: Values in the rows followed by the same letter (s) are not significantly different ($p < 0.05$) according to Tukey test.

Discussion

In the present study, mean $\overline{H}$ values ranged between 1.81 on NW aspect of *Q. floribunda* forest and 0.41 on NE aspect of *P. roxburghii* forest. The values of species diversity are in agreement with those reported for other temperate forests. The mean $\overline{H}$ values reported for the forests of Uttarakhand Himalaya vary from 0.08 to 1.29 (Shivnath et al. 1993) and 1.55 to 1.97 (Mishra et al. 2000). In pure *Pinus roxburghii* forest type, the value of C_d was the highest on SW aspect, which indicates a mono-specific forest type. In the present study, mean C_d ranged between 0.85 on NE aspect of *P. roxburghii* forest and 0.34 on SW aspect of *Q. floribunda* forest. The values of C_d of the present study were more or less similar to the earlier reported values for other temperate forests. In an earlier study the mean C_d values of 0.31 to 0.42 (Mishra et al. 2000) and 0.07 to 0.25 (Shivnath et al. 1993) were reported from different parts of Uttarakhand Himalaya. The higher values of C_d in forests were due to lower species richness. According to Baduni and Sharma (1997), the C_d or Simpson index was strongly affected by the Importance Value Index of the first three relatively important species in a community. Whittaker (1965) reported that the values of C_d for certain temperate vegetation ranged from 0.19 to 0.99. The lowest equitability was found on SW aspect of pure *Pinus roxburghii* forest type, which may be due to monospecific nature of the forest and dominance of a single species. The lower species diversity and consequently greater concentration of dominance of species on south-west aspect could be due to prevalence of drier conditions. Species diversity (richness) and dominance (Simpson index) of species are inversely related to each other (Zobel et al. 1976). The higher values of Shannon-Wiener diversity index and Simpson's diversity index on northern aspects and higher values of C_d on southern aspects have been reported in this study, which may be attributed to prevalence of drier spurs on southern aspects as compared to northern aspects. The higher TBC values on northern aspects in all the forest types as compared to southern aspects on the other hand can be attributed to occurrence of moister and favorable environment on the northern aspects.

The soil and vegetation have a complex interrelation, because they develop together over a long period of time. The selective absorption of nutrient elements by different tree species and their capacities to return them to the soil bring about changes in soil properties (Singh et al. 1986). The natural forest-stands of any places are the resultant of the interaction of various factors for the soil and the environment. The quantum of biomass produced over a period of time depends largely on the nature, aggregation of species, and the nutrient supply potential of the soil. On the other hand, the forests also have a marked influence on the growth and development of soils. The lower moisture content and water holding capacity of the soils on southern aspects as compared to the northern aspects indicate relatively drier conditions on the southern aspects. This is because north-east aspects are generally moister and cooler as compared to the south-west aspects, which also affects various other soil properties. On southern aspects of pine forests in Garhwal Himalaya, frequent fires are common. This is owing to the high inflammability of igniting material due to a low water content and high surrounding temperature. The violent fires especially in the summer season results in the rapid deterioration of soil fertility, minimizing the possibility of invasion by new species. This helps in dominance of fire hardy pine forests on lower elevations and southern aspects. It can also be considered as the main cause of higher stem density and lower TBC of pine on southern aspects as compared to northern aspects. According to Banerjee and Chand (1981), burning in these forests led to an immediate reduction in total organic matter ranging from 33% to 50% and lowered the availability of phosphorus and potassium also.

Soil nitrogen is supposed to be the most limiting nutrient in a majority of ecosystems (Fenn et al. 1998). Ecologists have long considered temperate forests systems to be limited by nitrogen (N) availability (Mitchell and Chandler 1939). In this study, available N has not shown any specific trend as far as slope aspect is concerned, but among forest types it varied significantly. The highest available N was recorded in *P. roxburghii* forest type, followed by *C. deodara* forest and all the other forest types had more or less similar amounts of available N. There was no specific trend in phosphorus availability on different aspects of the studied forest types. It has been reported that a large proportion of phosphorus is stored in forms which are unavailable to plants (Murphy 1958). For example, H_2PO_4 which becomes available at low pH value, suffers from fixation by hydrous oxides and silicate minerals (Soromessa et al. 2004). This phenomenon may explain the low phosphorus contents encountered in the soil samples collected from the study sites. We have found that the higher amount of organic carbon in the soil is available on cooler and moister northern aspects, which is probably the cause for revealing higher productivity (here represented by TBC) on these aspects.

Conclusion

The results show that forest stands growing on northern aspects are more productive (e.g. total basal cover) and have better soil properties as compared to southern aspects. Therefore, we recommend that plantation of these forest types can be undertaken on the northern aspects for better results in the Himalayan temperate forests. Moreover, forest stands growing on the northern slope aspects should also be given priority in conservation programmes.

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